AD-A047 735 VIRGINIA POLYTECHNIC INST AND STATE UNIV BLACKSBURG --ETC F/G 20/11
AN EXPERIMENTAL STUDY OF SURFACE TEMPERATURES GENERATED AT THE --ETC(U)
NOV 77 M J FUREY DA-ARO-D-31-124-73-G146

UNCLASSIFIED VPI-E-77-27 ARO-10887.1-E NL

| OF |

AD
A047 735

END
DATE
FILMED
1 -78
DDC

(12)

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

VPI-E-77-27

Final Report
on the Project

An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface[1]

by

Dr. Michael J. Furey[2]
Department of Mechanical Engineering

November 1977

[1]U. S. Army Research Office, Grant Number DA-ARO-D-31-124-73-G146;
ARO Proposal Number P-10887-E.

[2]Professor and Principal Investigator

Approved for public release; distribution unlimited

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

CONTENTS

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Mechanical Engineering Department
Virginia Polytechnic Institute & State University
Blacksburg, Virginia 24061

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

------(NA)

3. REPORT TITLE

(6) An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

(9) Final Report.

5. AUTHOR(S) (First name, middle initial, last name)

(10)

Dr. Michael J. Furey Professor and Principal Investigator

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
(11) November 1977	18	16

(15) 8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DA-ARO-D-31-124-73-G146	Final Report
b. PROJECT NO. (12) 23p.	
c. Proposal No. P-10887-E	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	(14) VPI-E-77-27

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

(18) ARO

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None (19) 10887.1-E	U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709

13. ABSTRACT

This is a final report on the first phase of an experimental investigation of surface temperatures generated by sliding contact between solids. Emphasis is on the determination of surface temperatures by means of a geometrically simple but functionally sophisticated device built around the use of an infrared microscope. The device consists basically of a fixed specimen (e.g., sphere, cylinder, flat, or cone) loaded against a thin rotating disc transparent to infrared radiation, in this case an optically flat sapphire disc 1mm thick. Since the target spot size is much smaller than the region of macroscopic elastic or plastic contact, it is possible to scan the contact region by moving the infrared microscope very precisely in the horizontal x-y plane. With this apparatus, applied loads can be varied from 0.1 to 10N while sliding velocities from 10^{-3} to more than 10m/s can be achieved. Measurements made include radiance, emissivity, friction, and area of contact and surface damage information obtained from scanning electron micrographs ~~(U)~~.

.001

Using this method, the surface temperature and tribological behavior of several model systems (e.g., various polymers, graphite) was investigated and the results compared with existing theory. Although the accurate determination of surface temperatures from radiance measurements is a difficult task with many pitfalls and sources of error, valuable fundamental information can be obtained with this technique if one exercises care, ingenuity, and calibration of the system actually used. As an example, it has been possible (a) to measure the detailed temperature distribution over a tiny region of elastic (Hertz) or plastic contact in a dry sliding system and (b) to relate this information to real areas of contact--two of the most important unknowns in tribology. To our knowledge, this has not been done before (U).

DD FORM 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

404 100

14. KEY WORDS (AND PHRASES)	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tribology						
Friction, wear, and lubrication						
Contact between solids; contact phenomena; solid-solid contact						
Temperature of rubbing surfaces						
Frictional heating in interfacial contact						
Thermal aspects of solid-solid contact						
Energy distribution at interfacial contacts						
Moving sources of heat and the temperature of sliding contacts						
Surface temperatures generated by friction, solid-solid contact, or other tribological processes.						
Mean rise in surface temperature; maximum rise						
Experimental study of surface temperatures caused by frictional contact						
Infrared techniques for measuring surface temperatures generated by friction						
Infrared, radiance, and emissivity in measuring frictionally-produced surface temperatures						

THE PROBLEM

One of the most important unknowns in tribology--the study of friction, wear, and lubrication--is the temperature of the surfaces. We know, for example, that surfaces get hot when rubbed together. But an important question is how hot do these surfaces actually get, and what effects do these temperatures have on wear, lubrication, and other surface phenomena? Temperature affects the physical and chemical behavior of the rubbing solids; and of course it also affects the properties of the media between these solids. In fact, there is evidence that temperature may be a key not only to lubricant film failure (e.g., in elastohydrodynamic lubrication) but to the formation of effective antiwear films. Examples of the latter effect would include the thermal decomposition of the antiwear additive zinc dialkyldithiophosphate[1] and the intentional "in situ" formation of protective polymeric films on rubbing surfaces to reduce wear[2][3].

Theoretical studies on this problem have been made by Blok[4], Jaeger[5], Holm[6], Archard[7], Ling[8], and others. But unfortunately, good experimental data for comparisons with theory are meagre; it is a difficult and challenging task experimentally[9].

In brief, we know practically nothing about the magnitude and distribution of surface temperatures in real systems--whether dry or lubricated--and with diverse materials (e.g., metals, ceramics, polymers, inorganic and organic compounds, pure elements, etc.). If we did, it would aid in our understanding not only of the mechanisms by which wear occurs but also of the ways in which lubricants affect wear through chemical reactions with and in the vicinity of the rubbing solids. Surface temperatures are likely to play an important role in a variety of phenomena including materials processing and machining, polishing, the action of brakes, frictional welding, spark generation by friction, drilling through rock, gun-barrel erosion, and all tribochemical reactions. They may also be an important factor in the detonation of explosive materials either by accident or design.

RESEARCH GOALS

From a broad point of view, we therefore need to know more about all the various ways in which energy can be delivered to the solid-solid contact region (e.g., by friction, impact, deformation, shear of solids and of thin lubricant films). We also need to know more about the various ways in which this energy is distributed (e.g., by conduction) and absorbed (e.g., by heating of solids, melting, chemical reactions, etc.). This also implies that we need to examine the validity and weakness of existing surface temperature theory, in particular as it applies--or does not apply--to both dry and lubricated systems. These are the broad, and longer range goals of our research in this area.

The specific goals of the initial research carried out under this grant during a three-year period were:

(a) to examine in detail the problem of surface temperatures generated by relative motion between solids (e.g., sliding contact), with emphasis being placed on an advanced experimental investigation;

(b) to carry out the major part of this study by the design, construction, calibration, and use of an essentially simple sliding contact device which has as its key component a highly advanced infrared microscope;

(c) to examine the surface temperature and tribological behavior of some simple and well-characterized sliding systems as a beginning;

(d) to study possible reasons for the discrepancies that appear to exist between theory and experiment.

BASIC APPROACH USED

The basic approach used in this study was to design experiments in which one could determine the surface temperature of extremely small (and known) regions of contact under carefully controlled conditions; by knowing also the rate of energy input to the interface and the properties of the solids, comparisons could then be made with existing theory. In order to make such measurements, a valid and reliable experimental technique had to be developed; and this of course was the key to the entire study.

The first part of this project was devoted chiefly to the design, construction, operation, and calibration of the rotating disc/infrared microscope system. After this initial phase, certain changes and design modifications were found to be essential; these were made and the system re-evaluated.

The experimental device consists basically of a fixed specimen (e.g., a sphere or cylindrical flat) loaded against a rotating disc transparent to radiation (in this case, an optically flat sapphire disc 50 mm in diameter and 1 mm thick). Features of the apparatus include: (a) sliding velocities ranging from 10^{-3} to more than 10m/s (rotary disc speeds up to about 7200 rpm); (b) normal loads ranging from 0.1 to 10N; (c) friction measurement and continuous recording by means of a sensitive rotary torque transducer; (d) a precision X-Y table for moving the microscope in scanning across the contact region; (e) photographic arrangements for the optical channel of the infrared microscope; and (f) built-in arrangements for making transmissivity and emissivity measurements (e.g., of specimen surfaces, sapphire discs, blackbody calibration source). The heart (or eye) of the apparatus is a Barnes Infrared Radiometric Microscope (Model RM-2A) with a liquid nitrogen-cooled InSb detector, control unit, range extender, and instrument calibration source. Two Beck reflecting objectives are used, a 15X objective capable of measuring target spots of 3.56×10^{-5}m in diameter and a 36X objective capable of measuring target spots of 1.78×10^{-5}m in diameter. An extremely large range (10^4X) of constant rotary disc speeds is achieved by using a hysteresis synchronous motor and reduction gear belt drives. The entire rotating disc/IR microscope apparatus is mounted on a heavy base plate and special table to minimize vibration. [See Figures 1, 2, and 3 in Appendix]

SUMMARY OF THE MOST IMPORTANT RESULTS

1. The most important result of this research program is that we were able to measure the detailed surface temperature distribution over a tiny region of elastic contact (Hertz area) in a dry sliding system as well as in well-characterized systems in which several clearly-defined discrete areas of contact were formed. Furthermore, we have coupled this information on surface temperature distribution with measurements of the real area of contact--two of the most important unknowns in the field of tribology. To our knowledge, this has not been done before.
2. To achieve the above results, it was first necessary to design, construct, modify, and develop both the experimental apparatus and techniques used for determining surface temperatures in this manner; this is briefly described in the previous section. So in a chronological sense, this accomplishment was the most important result because everything else depended upon it.
3. The accurate determination of surface temperatures from radiance measurements is a difficult task with many pitfalls and sources of error. *In fact*, we have identified over 30 potential problems and sources of error in the use of IR techniques on this problem--many of these being anticipated. There are errors associated with (a) infrared measurements in general, (b) the use of the sapphire disc, and (c) sliding contact. But with care, ingenuity, proper calibration techniques, patience, and time, valuable fundamental information can be obtained with this method--information that, to our knowledge, cannot be obtained in any other way.
4. Surface temperatures generated at the solid-solid interface depend upon (a) the actual system used (e.g., the nature of the solids), (b) time, (c) applied load, (d) sliding velocity, and (e) location within the contact region.
5. Comparisons of experimentally-determined mean and maximum surface temperatures with those predicted from theory show that the use of existing theories in the conventional fashion can lead to very large errors. However, if one pays particular

attention to the real area of contact (e.g., as estimated from scanning electron micrographs), the mean experimental values for surface temperature rise are not far from those predicted by theory (e.g., Archard). This is most encouraging. However, all theories do not predict the same results and the situation with regard to maximum surface temperatures is not so favorable.

6. Comprehensive literature searches were completed in three areas, namely (a) theoretical treatments of surface temperatures generated by friction, (b) experimental techniques used on this problem, and (c) infrared methods of measuring surface temperatures.
7. Generalized computer programs based on Jaeger and Archard theories were developed for application to any system, any conditions, over a wide range of Peclet Numbers.
8. Key results of our findings were presented at international tribology conferences, including the Fourth and Fifth Limits of Lubrication Conference in London (1975 and 1977) as well as the Gordon Research Conference on Friction, Lubrication, and Wear (1976). Visits were also made to other laboratories involved in surface temperature research.
9. Assistance in this area was provided to Picatinny Arsenal, Feltman Research Laboratories, Explosives Division, notably Mr. Joseph Hershkowitz (Chief, Applied Physics Branch) and Dr. M. Y. Lanzerotti. After examining all our results, we are now at a point where we can very likely be of even further help; thus, we intend to send Picatinny a more comprehensive and detailed report of our techniques, problems, and results to date.
10. Using the rotating sapphire disc/infrared microscope device, the systems investigated under a wide range of loads and speeds included five polymers of varying structure and crystallinity and a very pure form of graphite. Although these systems were not expected to produce extremely high surface temperatures, mean rises of up to 150-200°C have been observed. More details may be found in the Appendix section SOME SPECIFIC CONTRIBUTIONS, a summary of results obtained by the Graduate Research Assistants who worked on this project.

ACKNOWLEDGEMENT

The Principal Investigator thanks the U.S. Army Research Office; Mr. James Murray, Director of the Engineering Sciences Division; Dr. Edward Saibel, Associate Director and scientific monitor; and Mr. Jack Harless, Chief of the Procurement Office, for their support, patience, and understanding throughout this research project. He also thanks Mr. Joseph Hershkowitz, Chief, Applied Physics Branch, Explosives Division, Feltman Research Laboratories, Picatinny Arsenal for his continued interest. Gratitude is also expressed to Mr. Ralph Dillon, Mr. Arnold Price, and machinists of Laboratory Support Services, VPI&SU, for their invaluable advice and help in constructing the rotating disc device. And to those colleagues with whom many fruitful discussions were held on theoretical and experimental problems in determining tribological surface temperatures, namely Professors Blok, Archard, Tabor, Cameron, Courtel, Godet, Winer, Quinn, Eiss, Wood, and others. Last, thanks are expressed to the graduate students who carried out the experimental work, namely Messrs. Wiggins, Rice, Omori, Li, and Richardson.

REFERENCES

1. Furey, M. J., "Friction, Wear, and Lubrication," Chapter 11, pp. 133-151 in Chemistry and Physics of Interfaces - II, published by the American Chemical Society, Washington, D. C. (1971). [See also Ind. & Eng. Chem., Vol. 61, No. 3, 12-29 March (1969)].

2. Furey, M. J., "The Formation of Polymeric Films Directly on Rubbing Surfaces to Reduce Wear," Proceedings of Conference on Physico-Chemical Mechanics of Friction and Wear, published by Soviet Academy of Sciences, Moscow, 1974. [See also Wear, Vol. 26, 1973, pp. 369-392]

3. Furey, M. J., "The 'in situ' Formation of Polymeric Films on Rubbing Surfaces," Proceedings in book form on International Conference on Polymers and Lubrication, published by Centre National de la Recherche Scientifique, Paris, 1975.

4. Blok, H., "Theoretical Study of Temperature Rise at Surfaces of Actual Contact Under Oiliness Lubricating Conditions," Inst. Mech. Eng., Proc. General Discussion Lubrication and Lubricants, 2, 222-35 (1937).

5. Jaeger, J. C., "Moving Sources of Heat and the Temperature at Sliding Contacts," Proc. Royal Soc. New South Wales, 56, 203-24 (1942).

6. Holm, R., "Calculation of the Temperature Development in a Contact Heated in the Contact Surface, and the Application to the Problem of the Temperature Rise in a Sliding Contact," J. Appl. Phys., 19, 361-6 (1948).

7. Archard, J. F., "The Temperature of Rubbing Surfaces," Wear, 2, 438-55 (1959).

8. Ling, F. F., and Ng, C. W., "On Temperatures at the Interfaces of Bodies in Sliding Contact," Proceedings of the 4th U. S. National Congress of Applied Mechanics, 1962, pp. 1343-9.

9. Furey, M. J., "Surface Temperatures in Sliding Contact," Transactions of the American Society of Lubrication Engineers, Vol. 7, 1964, pp. 133-146.

10. Wiggins, J. M., "An Experimental Method for Measuring Surface Temperatures Generated by Friction," Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1974.

11. Omori, D. I., "Infrared Measurements of Surface Temperatures in an Unlubricated Sliding System," Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1975.

12. Li, S. H., "Experimental Investigation of Surface Temperatures of Some Polymers in Unlubricated Sliding," Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1976.

13. Richardson, M. H., "An Experimental Investigation of the Surface Temperature of Graphite in a Sliding System Using an Infrared Microscope," Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1976.

14. Furey, M. J., Wiggins, J. M., and Rice, J. G., "Infrared Measurements of Surface Temperatures in Dry Sliding Contact: Technique and Sources of Error"*.

15. Furey, M. J., Omori, D. I., and Li, S. H., "Infrared Measurements of Surface Temperatures in Dry Sliding Contact: Polymers-on-Sapphire"*.

16. Furey, M. J., and Richardson, M. H., "Infrared Measurements of Surface Temperatures in Dry Sliding Contact: Graphite-on-Sapphire"*.

---

*Being completed but not yet submitted for publication. Will be submitted to ASLE-ASME Joint Lubrication Conference or the journal Wear.

TECHNICAL REPORTS

Furey, M. J., "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," Research Proposal Submitted to Army Research Office-Durham, February, 1972.

Furey, M. J., Progress Report No. 1 on Army Research Office Proposal No. P-10887-E, "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," April 1974.

Furey, M. J., Progress Report No. 2 on Army Research Office Proposal No. P-10887-E, "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," September 1974.

Furey, M. J., Outline of Research Results obtained (1 March 1974-1 March 1975) on AROD Surface Temperature Project, March 1975.

Furey, M. J., Progress Report No. 3 on Army Research Office Proposal No. P-10887-E, "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," April 1975.

Furey, M. J., Report on the 5-20 July 1975 Trip to England and France Relating to AROD Surface Temperature Project in Tribology, August 1975.

Furey, M. J., Progress Report No. 4 on Army Research Office Proposal No. P-10887-E, "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," September 1975.

Furey, M. J., Outline of Research Results Obtained (1 March 1975-1 March 1976) on AROD Surface Temperature Project, March 1976.

Furey, M. J., Progress Report No. 5 on Army Research Office Proposal No. P-10887-E, "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," April 1976.

Furey, M. J., Final Report on Army Research Office Proposal No. P-10887-E (Grant No. DA-ARO-D-31-124-73-G146) "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," November 1977 (this report).

LECTURES & TALKS

1. Furey, M. J., "An Experimental Study of Surface Temperatures Generated at the Solid-Solid Interface," U. S. Army Research Office Meeting on Fundamental Aspects of Wear, Erosion, Fretting, and Related Phenonema, Army Materials and Mechanics Research Center, Watertown, Massachusetts, 4-5 September 1974.

2. Furey, M. J., and J. G. Rice, and D. I. Omori, "The Measurement of Surface Temperatures Using Infrared Techniques," invited lecture, Fourth Limits of Lubrication Conference, Imperial College, London, 7-11 July 1975.

3. Furey, M. J., "Thermal Aspects of Film Formation by Antiwear Additives," invited lecture, Fourth Limits of Lubrication Conference, Imperial College, London, 7-11 July 1975.

4. Furey, M. J., "Infrared Measurements of Surface Temperatures in Dry and Lubricated Systems," invited talk, Gordon Research Conference on Friction, Lubrication, and Wear, Colby-Sawyer College, New London, New Hampshire, 14-18 June 1976.

5. Furey, M. J., "Behavior of Polymers in Sliding Systems: Friction, Wear, and Surface Temperature," guest lecture, Phillips Technical Seminar, Phillips Petroleum Company, Bartlesville, Oklahoma, 28 June 1976.

6. Furey, M. J., "Practical Problems in the Use of Surface Analytical Techniques in Real Lubricated Systems," lecture. ASLE Advanced Seminar on Physical, Chemical, and Topographical Characterization of Surfaces, Boston, Massachusetts, 8 October 1976.

7. Furey, M. J., "Recent Experimental Measurements of Surface Temperatures Using IR Methods," invited lecture, Fifth Limits of Lubrication Conference, Imperial College, London, 11-15 July 1977.

8. Furey, M. J., "Infrared Measurements of Surface Temperatures in Tribology," lecture, joint seminar of the University of Birmingham (Chemical Engineering and Metallurgy Departments) and the University of Aston (Physics Dept.), University of Birmingham, 20 July 1977.

9. Furey, M. J., "Surface Temperatures Produced by Friction," lecture, Department of Mechanical Engineering Seminar, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 14 November 1977.

LIST OF PERSONNEL AND DEGREES AWARDED

1. Dr. Michael J. Furey, Professor and Principal Investigator, Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia (10% time during first academic year, 20% time during the second and third academic years plus one month full time during each intervening summer).

2. Mr. James M. Wiggins, Graduate Research Assistant, completed requirements for the Master of Science degree in Mechanical Engineering, December 1974; degree awarded June 1975.

3. Mr. David I. Omori, Graduate Research Assistant, completed requirements for the Master of Science degree in Mechanical Engineering, August 1975; degree awarded June 1976.

4. Mr. Stephen H. Li, Graduate Research Assistant, completed requirements for the Master of Science degree in Mechanical Engineering, August 1976; degree awarded June 1977.

5. Mr. Melvin H. Richardson, Graduate Research Assistant, completed requirements for the Master of Science degree in Mechanical Engineering, August 1976; degree awarded June 1977.

6. Mr. James G. Rice, Instructor and Doctoral student, 50% time during summer, 1975.

ABSTRACTS OF THESES

1. AN EXPERIMENTAL METHOD FOR MEASURING SURFACE TEMPERATURES GENERATED BY FRICTION, by James Wiggins II, December 1974.

A device for measuring surface temperatures generated by friction was designed and constructed. The method consists of detecting and measuring the infrared radiation emanating from the frictional interface of a rotating sphere-on-flat mechanism.

The device uses an infrared-transparent sapphire disc as its rotating member. The infrared radiation is detected and converted to radiance by a Barnes Model RM-2A radiometric microscope. This instrument is capable of measuring the radiance of interfacial areas as small as 0.0008 cm in diameter. The radiance values are then mathematically converted to temperature. The sapphire disc is rotated by a system of gear pulleys and timing belts powered by a 125 watt motor. This system provides sphere-on-flat sliding speeds of 0.35 to 4500 cm/s. Friction is generated by loading a spherical test specimen against the bottom side of the rotating sapphire disc. The specimen is attached to one end of a lever-fulcrum mechanism. Loads of 0.1 to 10N can be applied to the disc by loading the other end of the lever.

After the construction of the device was completed some simple tests were conducted to observe the general performance of the machine. The test results along with suggestions for possible areas of improvement are discussed.

2. INFRARED MEASUREMENTS OF SURFACE TEMPERATURES IN AN UNLUBRICATED SLIDING SYSTEM, by David I. Omori, August 1975.

One of the most important unknowns when two contacting surfaces are in relative motion is the temperature distribution at the area of contact. To experimentally measure this surface temperature, a technique centered around the use of a highly advanced infrared microscope [i.e., the Barnes Radiometric Microscope] was developed and used.

The infrared microscope is capable of measuring the temperature of a very small area [e.g., 1.78×10^{-5} m in diameter for a 36X objective] which is many times smaller than the real area of contact. Thus, more detailed information on the area of contact [i.e., the temperature distribution] could be obtained from this technique than from previous methods.

The system that was first examined was a fixed polycaprolactam [i.e., Nylon 6] sphere loaded against a rotating sapphire disk. This combination provided a number of desirable features among which were the simple calculations of the elastic area of contact and the constancy of the plane of contact. Using this system, the effects of time, load, speed, and location in the area of contact on the radiance and surface temperature were investigated; comparisons between experimental results and existing theory were also made.

3. EXPERIMENTAL INVESTIGATION OF SURFACE TEMPERATURES OF SOME POLYMERS IN UNLUBRICATED SLIDING, by Stephen Li, August 1976.

An experimental method capable of measuring the instantaneous surface temperatures of very small areas (e.g., 1.778 x 10^{-5} m in diameter) was developed and used to investigate the frictional interface of a sliding system--a fixed polymer sphere loaded against a thin sapphire disk.

Basically, the method involves measuring the infrared radiance (which can be converted to temperature mathematically) from the contact area with a highly advanced infrared microscope. Friction at the interface is also obtained simultaneously.

In this research, the surface temperatures of four different polymers, namely high density polyethylene, polytetrafluoroethylene, polystyrene, and polymethylmethacrylate were investigated. Effects of load and sliding speed on the friction and wear behavior of the polymers were examined. Finally, the experimental results were compared with theoretical calculations, and reasons for the discrepancies were discussed.

4. AN EXPERIMENTAL INVESTIGATION OF THE SURFACE TEMPERATURE OF GRAPHITE IN A SLIDING SYSTEM USING AN INFRARED MICROSCOPE, by Melvin H. Richardson, August 1976.

Several very important problems remain unsolved in the field of Tribology. For example, we do not know the detailed nature and distribution of the real areas of contact when one solid body slides over another. Furthermore, we know very little about the actual surface temperatures produced in such systems. These two important unknowns are related and formed the basis for an investigation conducted at Virginia Polytechnic Institute and State University.

An experimental apparatus, using a sliding system, was constructed to study these problems. The sliding system consisted of SA-35 graphite test specimens loaded against a rotating sapphire disk. A scanning electron microscope was used to obtain detailed information on the size and shape of the areas of contact between the graphite and the sapphire. The surface temperature in the area of contact was determined by using a Barnes Infrared Microscope which measured the radiance from the area of contact. Since the target spot of the microscope was much smaller than the areas of contact, the temperature distribution over the microscopic area of contact could be determined. The results of the experimental study were compared with the temperature rises in the area of contact predicted by the theories of Blok, Archard, Jaeger, and Holm. Possible reasons for discrepancies between theory and experiment were also examined.

SOME SPECIFIC CONTRIBUTIONS

1. Wiggins (10) initiated the detailed design, development, and construction of the rotating disc device for measuring interfacial surface temperatures under a variety of static and dynamic conditions; this "first-generation" device was then tested and examined for future improvements. An initial computer program based on Archard's theory was also written.
2. Omori (11) made further improvements in the system and developed a test procedure for measuring radiance and surface temperature. He then used polycaprolactam (Nylon 6) against sapphire as a model system to investigate in detail. He found an effect of time on surface temperature which was paralleled by changes in friction and that increasing either the applied load or speed led to an increase in surface temperature; the rise in temperature was a function of the total rate of frictional heat supply (J/s). Experimental values for mean rises in surface temperature generally compared favorably with those predicted from Archard's theoretical treatment. [See Figure 4 in the Appendix]
3. Li (12) extended Omori's work by investigating the tribological and surface temperature behavior of four additional polymers varying in structure and degree of crystallinity, namely (a) polyethylene (high density), (b) polytetrafluoroethylene, (c) polystyrene, and (d) polymethylmethacrylate. He found that $\Delta T_s = CQ^n$ where ΔT_s = experimentally-determined mean rise in surface temperature, Q = total rate of frictional heat supply (fWV or J/s), C = a constant depending on the polymer, and n ranging from 0.74 to 0.92 depending on the polymer. Scanning electron micrographs of the worn surfaces of the polymers were used to estimate the "real" area of contact and this was found to increase with increasing load and speed. Comparisons with Archard's theory showed a more complex situation, i.e., for the more crystalline polymers, the assumption of elastic deformation provided reasonable agreement and theory; for the amorphous materials, the experimental values were always lower than the theoretical predictions. It was concluded that the most important single factor is the real

area of contact and how it is distributed.

4. Richardson (13) investigated the behavior of a pure graphite-on-sapphire system using spherical test specimens with a cylindrical protrusion of varying diameter. Emissivity of the graphite test specimens was measured using the infrared microscope and found to be a function of temperature, contact (with sapphire), and wear. The mean surface temperature rise increased markedly with increasing velocity and also as the diameter of the graphite specimens decreased. The latter effect is entirely unexpected. Comparisons with theory were made on the basis of contact area calculations made from (a) assuming plastic deformation, (b) shear strength and friction force (Bowden and Tabor adhesion theory), and (c) scanning electron micrographs of the graphite contact region. The results show the necessity of measuring or considering the real areas of contact in any study of surface temperatures produced by friction. These areas can best be approximated from scanning electron micrographs of the contact zone; calculated areas of contact from plastic deformation, for example, may lead to very large errors in calculated rises in surface temperature.

SUMMARY OF LIMITS OF LUBRICATION CONFERENCE PAPER

"The Measurement of Surface Temperatures
Using Infrared Techniques"

by M. J. Furey[1], J. G. Rice[2], and D. I. Omori[3]
Department of Mechanical Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

for presentation at the
Limits of Lubrication Conference
Imperial College
London, England
July 7-11, 1975

One of the most important unknowns in tribology is the temperature of the rubbing surfaces. Temperature affects the physical and chemical behavior of the rubbing solids and of that which is between the rubbing solids (e.g., lubricants). Unfortunately we know very little about the magnitude and distribution of surface temperatures in real systems, and this is due in part to the experimental difficulties involved.

During the past year, the authors have been working on a research project (funded by the U.S. Army Research Office) in which the emphasis is on the experimental determination of surface temperatures by means of a rather simple device built around the use of an infrared microscope. The device consists basically of a fixed specimen (e.g., a sphere) loaded against a rotating disc transparent to infrared radiation (in this case, a sapphire disc). Although this general approach has been used recently by Winer et al to determine oil film temperatures under elastohydrodynamic conditions, the emphasis in our study is on (a) dry systems for comparison with Blok, Jaeger, Archard (and modified) theory, and (b) chemical effects (e.g., in boundary lubrication) related to film-formation on rubbing surfaces.

This paper discusses two main areas, namely, problems in the use of infrared techniques for measuring surface temperatures generated by friction, and examples of recent results obtained with polymer-on-sapphire systems including comparisons with theory.

In brief, the accurate determination of surface temperatures from radiance measurements is a difficult task with many pitfalls and sources of error. But with care and ingenuity, valuable fundamental information can be obtained with this method. As an example, we have been able to measure the detailed temperature distribution over a tiny region of elastic contact (Hertz area) in a dry sliding system. To our knowledge, this has not been done before.

---

[1]Professor, [2]Instructor, [3]Graduate Assistant

BASIC CONTACT GEOMETRY

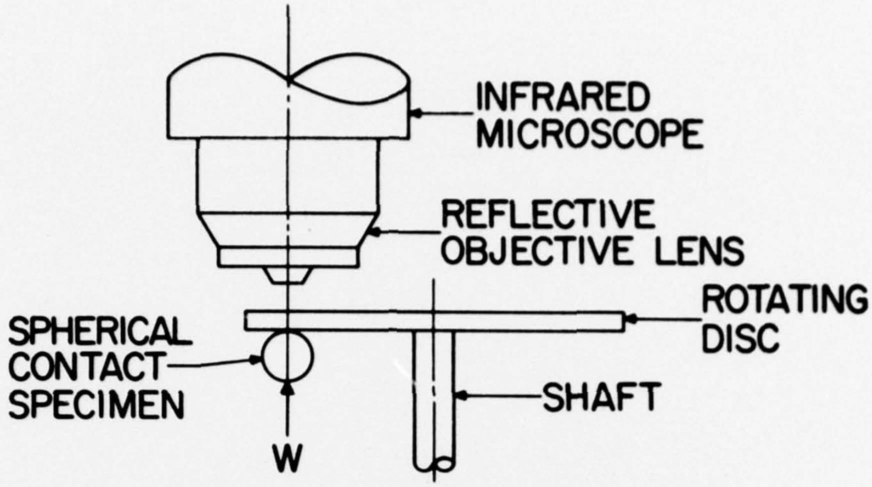

Figure 1. Contact Geometry in Rotating Disc/Infrared Microscope System

TEST CONDITIONS	
DISC	SAPPHIRE FLAT (1 mm THICK; 50mm DIAM.)
SPHERES	ANY MATERIAL (3 – 12 mm DIAM.)
LOAD	0.1 – 10 N
DISC SPEED	1 – 10,000 RPM
LOAD X SPEED	10^6 X
SLIDING VELOCITY	10^{-3} – 10 m/s

Figure 2. Range of Test Conditions Possible

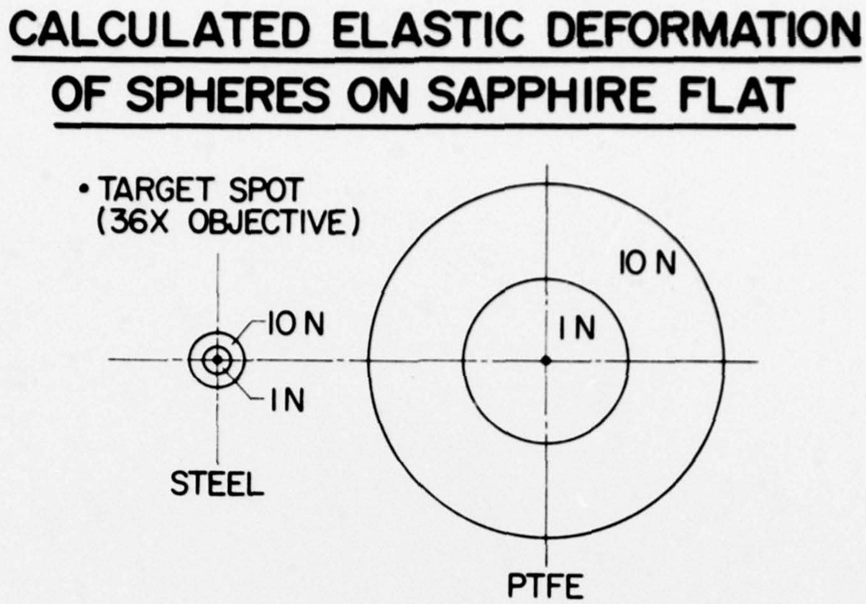

Figure 3. Comparison of Target Spot Size with Areas of Elastic Deformation

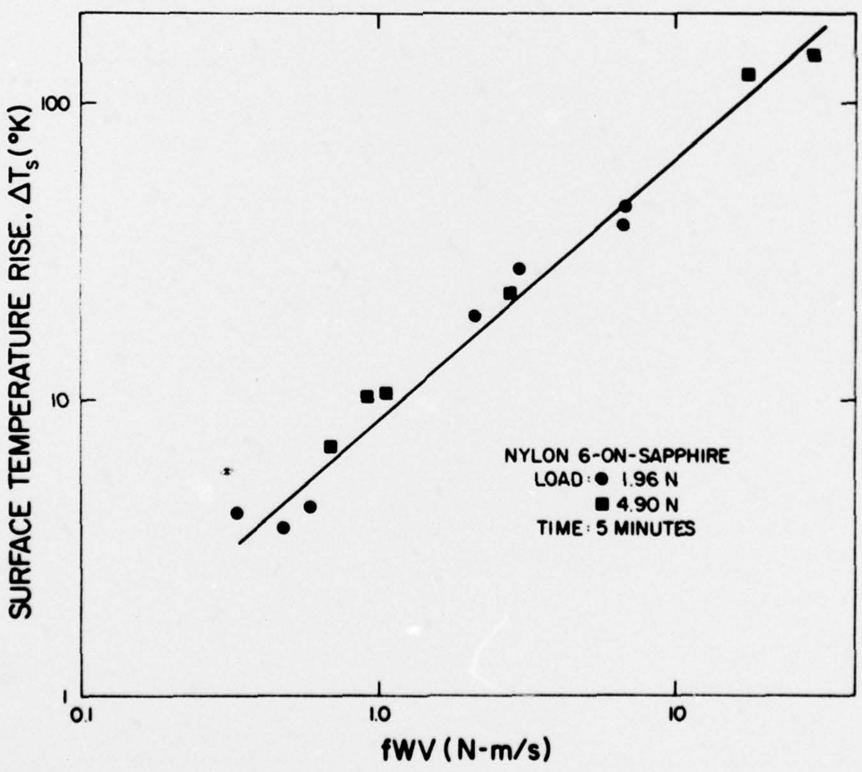

Figure 4. Example of Experimental Mean Surface Temperature Rise vs. Rate of Heat Supply